POSSIBILITIES OF USING VOID TO IMPROVE NATURAL CROSS VENTILATION IN HIGH-RISE LOW-COST RESIDENTIAL BUILDING (HRLCRB)

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To:

My beloved Wife & Children

(Nashatul Zaimah Noor Azman, Izzah Haziqah, Izzat Haziq & Izzat Hazim)

Thanks:

For all your Encouragement, Enthusiasm, Prayer, Patient, & Love for my Endeavour.

"Read! In the Name of your Lord who has created (all the exists). He has created man from a clot (a piece of thick coagulated blood). Read! And your Lord is most generous. Who has thought (the writing) by the pen. He has taught man that which he knew not". (96: 1-5)

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ABSTRACT

This thesis focuses on the study to investigate the possibilities of improving natural cross ventilation (in term of internal air velocity, m/s) in high-rise low-cost residential building (HRLCRB) in Kuala Lumpur. The HRLCRB design is found complied with the minimum requirement of natural ventilation in the Uniform Building Bye-Law (UBBL) and has architectural design that could permit optimum natural ventilation. However the natural ventilation and thermal comfort performance is still not achieved with respect to its internal air velocity performance. Cross ventilation has been suggested by many researchers as one of the most effective techniques of natural ventilation for thermal comfort. However, it is also one of the least understood parts in controlling indoor climate through passive design approach. In this thesis the proposed design solution is by introducing a void at specific floor level or height ratio of the HRLCRB. The research involves three stages. First, the inventory exercises. This is to determine the most basic and typical typology of HRLCRB built by Dewan Bandaraya Kuala Lumpur (DBKL). Second, computer simulation using Computational Fluid Dynamic (CFD) technique with specific software called FloVent. This software is used to estimate the vertical pressure distribution and to investigate the potential of the proposed design solution. Finally, empirical method is used to predict the internal air velocity. The result of the simplified building configuration is used as a basis of comparison. The result shows that the void affects the vertical pressure distribution. However, the effect is insignificant to improve the internal air velocity performance at the HRLCRB.

ABSTRAK

Fokus tesis ini adalah untuk menyelidik kemungkinan mempertingkatkan pengudaraan rentas semulajadi (dalam bentuk halaju angin dalaman, m/s) di perumahan kos rendah berbilang tingkat (PKRBT) di bandaraya Kuala Lumpur. Rekabentuk PKRBT didapati menepati keperluan minimum pengudaraan semulajadi yang dikehendaki di dalam Undang-undang Kecil Bangunan Seragam (UKBS) dan rekabentuk senibinanya memungkinkan pengudaraan semulajadi secara optima. Walau bagaimanapun prestasi pengudaraan semulajadi dan keselesaan termalnya masih tidak mencukupi merujuk kepada prestasi halaju angin dalaman. Pengudaraan rentas untuk keselesaan termal merupakan salah satu teknik pengudaraan semulajadi yang paling efektif sebagaimana yang telah dicadangkan oleh ramai penyelidik. Namun ia juga merupakan pendekatan pengawalan iklim dalaman melalui rekabentuk pasif yang paling kurang difahami. Di dalam tesis ini penyelesaian rekabentuk yang dicadangkan ialah dengan memperkenalkan lompang (void) pada tingkat khusus atau pada nisbah ketinggian tertentu PKRBT. Penyelidikan ini melibatkan tiga peringkat kajian. Pertama, melakukan inventori. Ini adalah untuk menentukan tipologi tipikal dan asas PKRBT yang telah dibina oleh Dewan Bandaraya Kuala Lumpur (DBKL). Kedua, simulasi komputer berteknikkan pengiraan bendalir dinamik atau Computational Fluid Dynamic (CFD) dengan menggunakan perisian khusus bernama FloVent. Perisian ini digunakan untuk menggangarkan nilai taburan vertikal tekanan angin dan menyelidiki potensi rekabentuk penyelesaian yang dicadangkan. Akhirnya, kaedah emiprikal digunakan untuk meramalkan halaju udara dalaman. Keputusan konfigurasi bangunan asas yang dipermudahkan telah digunakan sebagai perbandingan. Keputusan menunjukkan bahawa lompang memberi kesan kepada taburan vertikal tekanan angin. Walau bagaimanapun kesan tersebut masih terlalu kecil untuk memperbaiki prestasi halaju angin dalaman di PKRBT.

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LIST OF ABBREVIATIONS

ABL	-	Atmospheric Boundary Layer
ASCE	-	American Society of Civil Engineers
ASHRAE	-	American Society of Heating and Air-Conditioning Engineers
BFC	-	Body Fitted Coordinate
CAD	-	Computer Aided Design
CFD	-	Computational Fluid Dynamic
CIDB	-	Construction Industry Development Board
CIS	-	Construction Industry Standard
CPU	-	Central Processing Unit
DBKL	-	Dewan Bandaraya Kuala Lumpur (Kuala Lumpur City Hall)
FEM	-	Finite Element Method
FVM	-	Finite Volume Method
HRLCRB	-	High-Rise Low-Cost Residential Building
LES	-	Large Eddy Simulation
LW	-	Leeward
PA	-	Planning Area
PC	-	Personal Computer
PDE	-	Partial Differential Equation
PKRBT	-	Perumahan Kos Rendah Berbilang Tingkat
Pte. Ltd.	-	Private Limited
PWD	-	Public Work Department
RMK-6	-	Rancangan Malaysia Ke-6 (6th. Malaysian Plan)
RMK-7	-	Rancangan Malaysia Ke-7 (7th. Malaysian Plan)
SB	-	Single Block

SIMPLE	-	Semi-Implicit Method of Pressure-Linked Equation
TB	-	Twin Block
UBBL	-	Uniform Building Bye-Law
UiTM	-	University Technology Mara
UK	-	United Kingdom
UKBS	-	Undang-undang Kecil Bangunan Seragam
UMNO	-	United Malaya National Organisation
UPM	-	University Putra Malaysia
UTM	-	University Technology Malaysia
WW	-	Windward
3-D	-	Three Dimensional
2-D	-	Two Dimensional

LIST OF SYMBOLS

A	-	Flow area, (m^2)
ACH	-	Air Change Rate
α	-	An empirical exponent which depends on the surface roughness, stability and temperature gradient.
C	-	Dynamic loss coefficient
c	-	Concentration of the secondary medium, (kg/s)
°C	-	Degree Celsius
Cd	-	Discharge coefficient of opening
ΔCp	-	Pressure coefficient difference, (dimensionless)
C_p	-	Specific heat capacity, (J/(kgK))
D	-	Laminar diffusivity, (m^2/s)
D_{eff}	-	Effective diffusivity, (laminar plus turbulent), (m^2/s)
D_t	-	Turbulent diffusivity, (m^2/s)
k-ε	-	Turbulence kinetic energy – dissipation rate (Reynolds average method)
m/s	-	Meter per Second
m^3/s	-	Meter Cube per Second
φ	-	Dependent variable
p	-	Pressure, (Pa)
ρ	-	Air density, (kg/m^3)
ΔP	-	Pressure difference across opening, (Pa)
P_1	-	Wind pressure at windward façade
P_2	-	Wind pressure at leeward facade
$P_ı$	-	Mean surface pressure at the building envelope (h height)
P_ℓ	-	Pressure loss through a single opening

P_{ref}	-	Reference pressure at roof height (h1)
Q_{pi}	-	Predicted internal airflow rate
Re	-	Reynolds Number
S_{φ}	-	Source
T	-	Temperature, (K)
t	-	Time, (s)
Γ_{φ}	-	Exchange coefficient
μ	-	Laminar viscosity, (kg/(sm))
μ_{eff}	-	Effective dynamic viscosity, (laminar plus turbulent), (kg/(sm))
μ_t	-	Turbulent viscosity, (kg/(sm))
V	-	Wind speed at h height
v, u, w	-	Air velocity in x, y, z direction respectively, (m/s)
$\acute{\upsilon}$	-	Velocity vector
V_g	-	Height where the gradient wind starts
V_{h1}	-	wind speed (m/s) at height h1 (m)
V_{pi}	-	Predicted internal air velocity or the mean wind speed through the opening in the building (m/s)
V_{ref}	-	The reference wind speed at a height used to determine pressure coefficients (Cp_1 and Cp_2) or mean wind speed at some reference height Z_{ref}
V_z	-	The mean wind speed at height z
-ve	-	Negative
+ve	-	Positive
λ	-	Laminar thermal conductivity, (W/(mK)
λ_{eff}	-	effective thermal conductivity, (laminar plus turbulent), (W/(mK))
λ_t	-	Turbulent thermal conductivity, (W/(mK)
Z	-	The height for which the wind speed Vz is computed
Z_{ref}	-	The reference height
Z_g	-	The height for which the wind speed V_z is computed (Gradient height)
Z_o	-	Roughness length or log layer constant

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CHAPTER I

INTRODUCTION

This thesis explores the potential of improving natural cross ventilation through induced wind pressure in order to provide human thermal comfort in high-rise low-cost residential building (HRLCRB) in Kuala Lumpur.

Even though the design of low cost houses complies with the requirement of Uniform Building Bye-Law (UBBL) (UBBL, 1984) with regard to natural ventilation, researches (Pan, 1997; Tan, 1997; Jones, *et.al.*, 1993 & 1994; Zulkifli, *et.al.*, 1991; Zulkifli, 1992a, 1992b, 1994a, 1994b; Hui, 1998; Abdul Razak, *et. al.*, 2000, 2001) have shown that its natural ventilation performance could not provide internal thermal comfort. In theory, the natural phenomenon of gradient wind is higher at the upper atmosphere (ASHRAE, 1997). This gives advantages to the high-rise building in providing natural cross ventilation. However, in the case of HRLCRB this has not been investigated. Therefore, investigation to promote and upgrade the natural ventilation performance of HRLCRB should be carried out.

1.1 Background

House is one of the three basic needs in human life. The function of a house covers physical and non-physical aspects. As a shelter, house protects us against climatic elements and provides comfortable, safe and defensible domains.

Housing in Malaysia is growing rapidly. The growth of the housing industry in this country especially in urban areas is basically caused by two main factors; firstly, the population and secondly, the economic and industrial growth (Mohd. Razali, 2001).

1. Based on the demographic data and the Malaysia economic growth, the population density of Malaysia is estimated to be 70 million by the year 2020. As reported by Utusan Malaysia on January 4th. 2001 (Laupa, 2001), to date the population is estimated around 22 million. This number is expected to increase every year.

2. In the last century, Malaysia especially in major cities such as Kuala Lumpur faced rapid economic and industrial growth. These factors attracted the poor to migrate from rural areas. The migration of this group of people to urban area in search for a better living caused high demand of houses especially the low-cost type (Ghani and Lee, 1997; Mohd. Razali, 1997 & 2001).

In Malaysia the high demand of houses can be seen from the projection of houses to be built by both public and private sectors. In 6th. Malaysian Plan (RMK-6, 1991), 647,460 units of houses were built. In 7th. Malaysian Plan (RMK-7, 1996), 800,000 units are projected to be built. These show an increase of 152, 540 units to be built within the 5-year plan.

In general, the demand of houses is always increasing. However, the expeditious increase in the construction of houses especially the low cost houses has left behind the environmental and sustainable design issues especially with regards to natural ventilation. The low-cost houses are not designed to be environmental friendly; thus, thermally not comfortable to live in (Abdul Malik, 1995). Figure 1.1 shows the effects of uncomfortable houses to the social, economic, health and energy sectors. One of the contributors to the effect is the poor natural ventilation performance at the houses.

Therefore, the houses designed especially for the low income groups require more energy conscious due to the fact that they could not afford extra expenditure to buy mechanical appliances or to pay high electric bill. Nevertheless, there is a need for a comfortable house for the low-income family especially in urban environment. Hence, consideration should be given in improving the planning and design of the low-cost houses. The houses should be more environmental friendly and must be provided with optimum natural ventilation and thermal comfort.

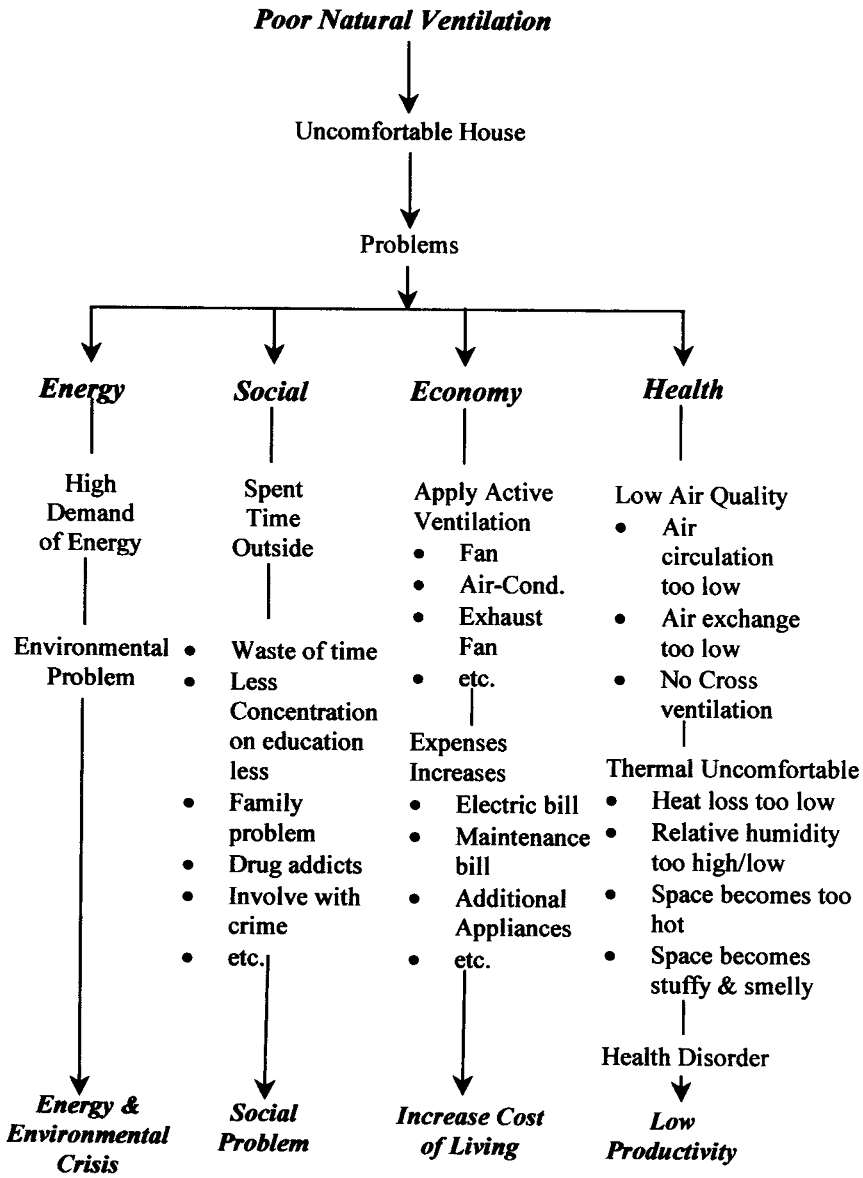

Figure 1.1: The Effects of Poor Natural Ventilation to the Social, Economic, Health and Energy Sectors.

1.2 Research Objective

It is essential to solve the issue of natural ventilation and thermal comfort in order to achieve a better living standard for the low-income groups. The primary objective of this thesis is to investigate and evaluate the possibilities of void in improving natural cross ventilation in high-rise low cost residential building (HRLCRB).

The specific objectives of the thesis are;

1. To estimate the external wind pressure distribution caused by the following design parameters:
   a. The introduction of void at specific floor level.
   b. Building orientation.

2. To predict the internal air velocity (V) for the proposed design mentioned in (1).

3. To validate the performance and the effectiveness of the proposed design mentioned in (1) in improving natural cross ventilation in HRLCRB.

1.3 Scope and limitation of the Research

This study focuses on the natural cross ventilation for human thermal comfort. Wind pressure converted to pressure coefficient (Cp) estimated at the surface of the HRLCRB envelope is used to predict the natural cross ventilation performance.

Computational Fluid Dynamic (CFD) is selected as the primary tool in this study due the flexibility, reliability and accuracy of this tool as an alternative method to study airflow around building as well as to estimate the pressure distribution (Baskaran, A. and Stathopoulos, T., 1989 & 1992; Murakami, S. and Mochida, A., 1989; Murakami, S. *et. al.*, 1999; Jones, P.J. and Whittle, G.E., 1992; Chen, Q., 1992; Satwiko, P., Locke, N. and Donn, M., 1998; Mathews, E.H and Rousseau, P.G., 1994.). In this thesis, advanced and specific CFD software for environmental studies called FloVent from Flomeric Inc. United Kingdom is used in the estimation of vertical pressure distribution due to wind flow around HRLCRB building.

A simplified building from of HRLCRB in Kuala Lumpur built by Dewan Bandaraya Kuala Lumpur (DBKL) is used in the simulation exercise. This building form is determined through an inventory and case study exercises. For predicting the internal air velocity performance of the proposed design solution, empirical method proposed by Aynsley, *et.al.,* (1977) is used.

Wind pressure distribution estimated from the CFD analysis is used in determining the natural ventilation of the proposed building configurations. A bluff body model based on a simplified form of HRLCRB is simulated in a boundary layer wind environment. The effect of other shapes will not be investigated in this thesis. Furthermore, the effects of different building elements such as building projections (balcony, sun shading and corridors) and openings (sizes, height, position) will also not be investigated. The effect of urban proximity also will not be covered in this thesis. In general, the "building" in this building is referred to as a sealed model at an isolated condition with uniform openings.

1.4 Significance of the Research

The issues of environment, social, health and productivity as summarized in figure 1.1 justify the importance to conduct this research.

i. The occupants of HRLCRB will benefit through thermally comfortable houses. As a result, their lives will be healthier and productive (Evans, 1982). This will upgrade their standard of living and encourage a closer family relationship.

ii. At a national level, this research will contribute towards producing thermally comfortable homes naturally without consuming any generated energy (Wan Nadia and Hj. Hoesni, 2002).

iii. For a designer, practitioner, developer as well as policy maker, the findings of this research can be used as a guide to further develop and design more comfortable low cost houses especially the high-rise residential buildings.

1.5 Thesis Organization

In answering the research questions and achieving the research aim, the following tasks have been identified and carried out. This can be divided into four main parts. The overall thesis methodology is shown in figure 1.2.

1. Theoretical research that covers a basic understanding of the design parameters affecting natural ventilation studies especially for cross ventilation. The theories also cover an understanding of the environmental design of high-rise building especially the high-rise residential buildings and the relationship of wind and buildings. This part also covers the methods in investigating wind induced natural ventilation.

2. Background study of the high-rise low-cost residential buildings in Kuala Lumpur. This part covers the literature review, inventory and compilation exercise to define the HRLCRB and its basic form developed and built by DBKL. A case study to investigate the actual and current natural ventilation and thermal comfort performance at HRLCRB is also carried out. The potential of wind induced natural ventilation will be analyzed in this part.

3. Natural Ventilation simulation. A computer simulation using Computational Fluid Dynamic (CFD) software called FloVent is used to study the effect of the external wind condition and pressure distribution in relation to various design parameters proposed.

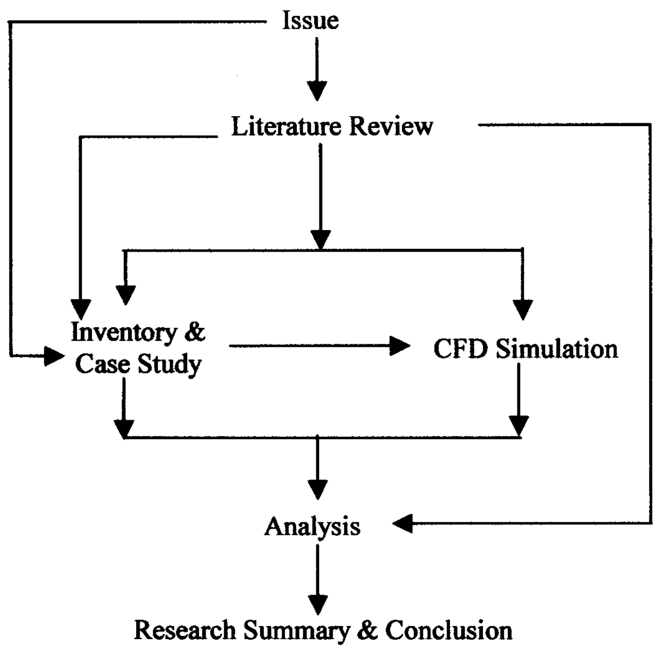

Figure 1.2: Overall Thesis Methodology

4. In relation to the findings in (3), further evaluation on the pressure data obtained is carried out to predict the natural ventilation performance in terms of internal air velocity. This is very important to justify whether the generated internal air velocity is capable to assist thermal comfort. In carrying out this task empirical method proposed by Aynsley, *et. al.,* (1977) is used.

1.6 Definition

1.6.1 High-Rise

High-rise can be termed as a multi storey or tall building or skyscrapers (Flamming, 1991). Dictionary of Building defined high-rise as a tall building having the height more than eight storeys and at least 28 meters from the street level to the roof top (MacLean, 1993). Orton (1988) defined high-rise buildings that is at least 20 storeys in height and has a ratio of height to least width that exceeds 5 (height: width > 5:1).

ASHRAE (1997) defined high-rise buildings as where the height (H) is more than three times the crosswind width (W): H>3W (figure 1.3(a)). Cook (1990) defined tall or high-rise buildings as buildings that the ratios are 2H/B > 1, where (H) is the height and (B) is the length (figure 1.3(b)).

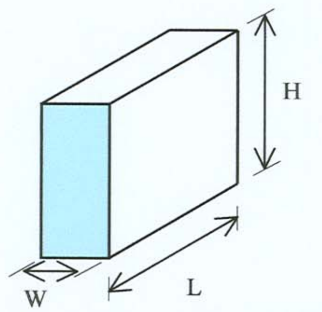

Figure 1.3(a): High-Rise as Defined by ASHRAE (1997)

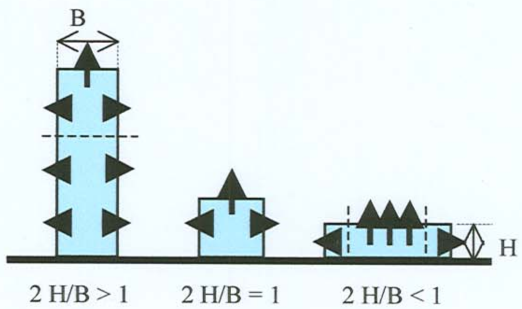

Figure 1.3(b): High-Rise as Defined by Cook (1990)

Figure 1.3: High-Rise Definition by ASHRAE (1997) and Cook (1990)

1.6.2 Basic Configuration of High-Rise Residential Building

There is no specific definition for basic form of high-rise residential buildings. However, Boutet (1987) listed five primary forms/shapes of residential building design. They are square, rectangular or linear, U-shape, L-shape and T-shape. Rectangular or linear building shape is the most basic configuration of high-rise residential buildings.

From the aspect of climatic performance, Givoni (1998) divided high-rise residential buildings into two categories;

a. Buildings with long corridors providing access to the units along them. Staircases or elevators provide vertical access to the corridors.

b. Buildings with staircases or elevators providing direct access to two, three or four units or known as a cluster type.

Between these two types, the former is simpler and straightforward in terms of the vertical and horizontal circulations. This type can be classified further into:

a. Single Loaded Corridor Type (Figure 1.4).
   Buildings with an external corridor located along one wall of the building
b. Double Loaded Corridor Type (Figure 1.5).
   Buildings with an internal corridor, providing access to units on both sides

From this explanation it can be defined that the most basic configuration of high-rise residential building is rectangular or linear in shape and has a single-loaded corridor.

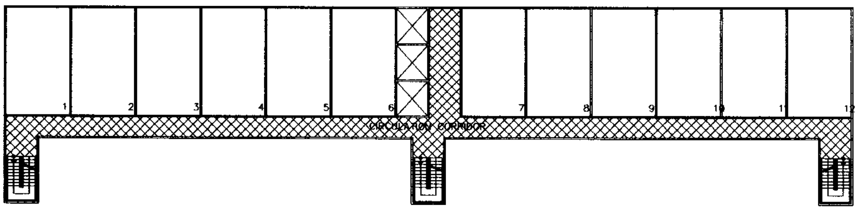

Figure 1.4: Example of High-rise Single Loaded Corridor Type

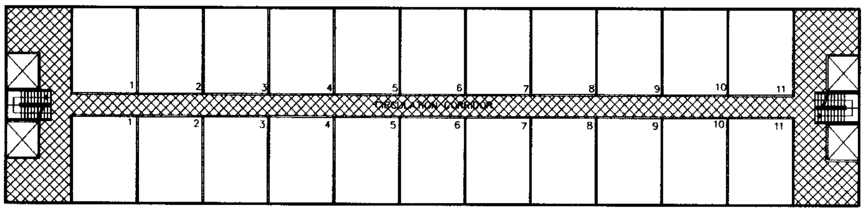

Figure 1.5: Example of High-rise Double Loaded Corridor Type

1.6.3 Low Cost Residential Building

Low cost residential buildings, according to the Ministry of Housing and Local Government (MoHLG) are houses meant for low-income people. The low-income people are defined as people with household monthly income between RM 750.00 and RM1500.00 (MoHLG, 1998). The price of the houses also varies based on locality. In general, the price should not exceed RM 42,000.00 in the city area (MoHLG, 1998). The type of the low-cost residential buildings also varies based on the locality and cost of construction. In urban areas such as Kuala Lumpur, Penang and Johor Bahru the demand for this type of houses are very high due to the rural-urban migration. In the city, the land price, materials and labour cost are also high. Therefore, the type of houses being constructed here is normally more towards the high-rise buildings.

1.7 Outline of the Thesis

This thesis is divided into five chapters. A brief introduction to the overall thesis and its contents are presented in this chapter identified as **Chapter I.**

Chapter II presents the natural ventilation background study. This chapter covers a basic understanding of natural ventilation, human thermal comfort and the design parameters that affect wind climates and natural ventilation. The study also covers the concept and work related to architectural design that affect natural ventilation especially at high-rise building that have been carried out by other researchers. Finally, the research gap and concept in the area of study is identified and the research hypothesis is laid down.

Chapter III discusses the methodology used in investigating the possibilities of using void to improve natural cross ventilation at HRLCRB due to wind pressure differences. Literature reviews on the work done by previous researchers in wind, natural ventilation and cross ventilation are also deliberated. The justification of selecting the methodology for this study is also elaborated. This chapter also describes the methodology involved in the CFD simulation. This chapter illustrates and describes all the scale models, procedures, conditions and setting-up of the CFD simulation. The reliability and validity of the methods, equipments and simulation procedures are also discussed. The estimation of the specific discharge coefficient (Cd) value for the research is also presented. The results obtained from the simulation exercise are presented in the following chapter.

Next in **Chapter IV**, the results obtained from the simulation exercise is presented and analysed. This includes comparative analysis of the predicted internal air velocity obtained from the proposed design solution with the required internal air velocity for thermal comfort in hot and humid country with special reference to Kuala Lumpur urban climate. The summary of the major findings is also presented in this chapter.

Finally, **Chapter V** concludes the thesis. The overall research summary is presented in this chapter. It also outlines the suggestions for future research on natural ventilation study especially on areas of limitation of this study.